

Merging the real with the virtual

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Merging the Real with the Virtual: Crowd Behaviour Mining with Virtual Environments

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Abstract—The first recorded crowdsourcing activity was in 1714 [1], with intermittent public event occurrences up until the millennium when such activities become widespread, spanning multiple domains. Crowdsourcing, however, is relatively novel as a methodology within virtual environment studies, in archaeology, and within the heritage domains where this research is focused. The studies that are being conducted are few and far between in comparison to other areas. This paper aims to develop a recent concept in crowdsourcing work termed ‘crowd behaviour mining’ [2] using virtual environments, and to develop a unique concept in crowdsourcing activities that can be applied beyond the case studies presented here and to other domains that involve human behaviour as independent variables. The case studies described here use data from experiments involving separate heritage projects and conducted during two Royal Society Summer Science Exhibitions, in 2012 and 2015 respectively. ‘Crowd Behaviour Mining’ analysis demonstrated a capacity to inform research in respect of potential patterns and trends across space and time as well as preferences between demographic user groups and the influence of experimenters during the experiments.

keywords—crowdsourcing, crowd behaviour mining, virtual environments, landscape archaeology, digital heritage

I. INTRODUCTION

A crowdsourcing scoping study conducted by the Arts and Humanities Research Council (AHRC) outlined the importance of engaging the crowd within Humanities

research [3]. Crowdsourcing, a term coined in 2005 [4] has become a popular participant activity within the last decade and a widely used crowdsourcing definition was provided in 2012 [5], there crowdsourcing is interpreted as an activity that segments large tasks into sub-tasks, which participants resolve by distributing work amongst themselves. Crowd sourced work takes advantage of the motor skills, or the intelligence of crowds as a collective contribution. Crowd sourced projects can solve highly complex problems, and case studies have shown that crowd sourced projects produce patterns that are extremely stable [6].

A Google Trend keyword search for ‘crowdsourcing’ and ‘crowdfunding’ (Figure 1: Top) demonstrates an increase in Google keyword search for ‘crowdsourcing’ since 2005, peaking around 2014 – after which its use dwindles slightly. However, such a decrease does not necessarily equal a loss of interest, it may simply mean that the general population has become rather familiar with the concept. ‘Crowdfunding’ on the other hand, has attracted considerable interest. This is also suggested by considering the list of ‘Timeline of Major Events’ in the ‘Crowdsourcing’ Wikipedia page we generated as a graph (Figure 1: Bottom) which runs from 1714 up until 2006 with x =Actual Year of Occurrence and y =Years Between Major Event Occurrence (a calculated difference between the present year x and the last event $x-1$). While this does not represent all recorded activities globally, the graph suggests that there has been an increase in major crowdsourcing activity within the decade up until 2006, with significant activities around the year 2000.

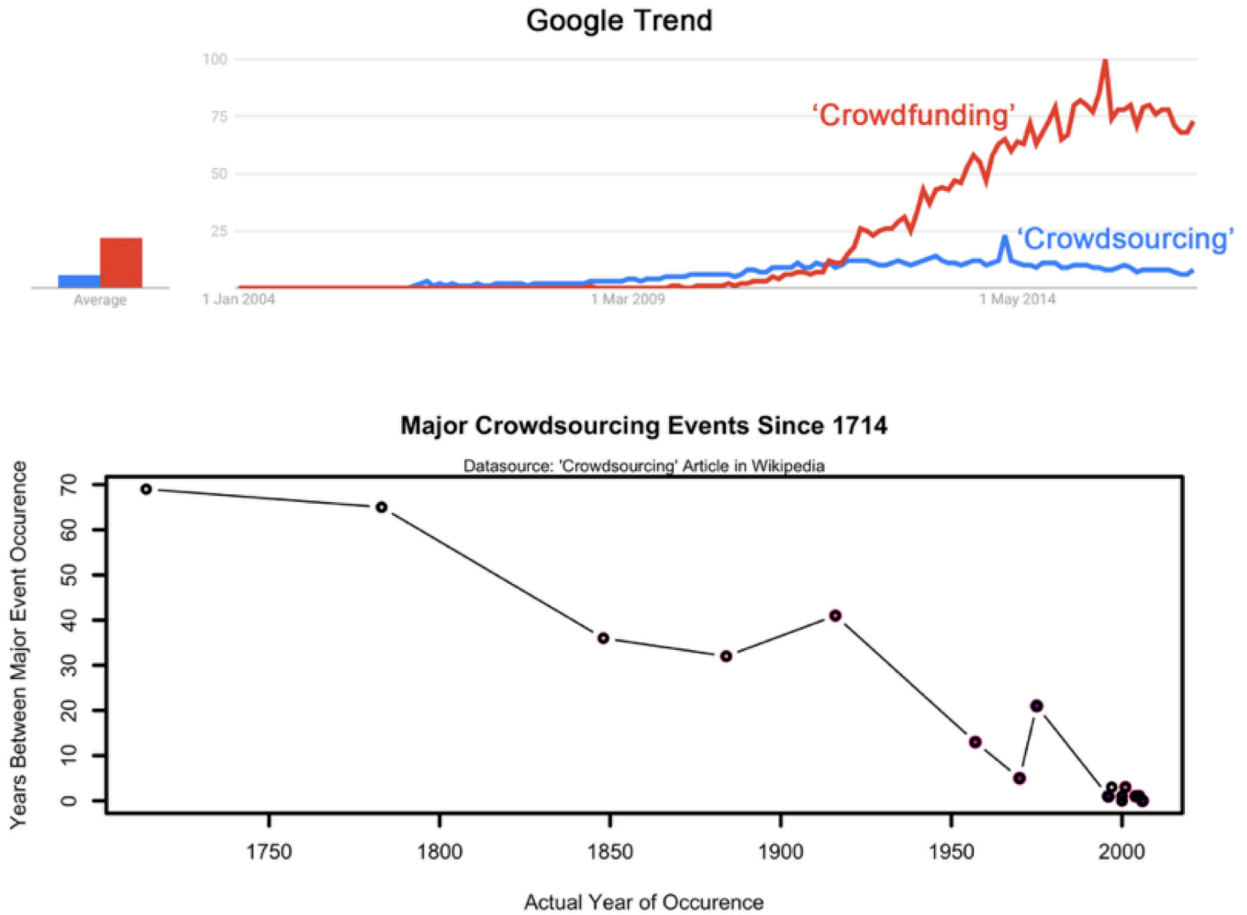


Fig. 1. Google search trends for the keywords 'crowdsourcing' and 'crowd funding' (Top). Major crowdsourcing events since 1714 (bottom) showing major Event Occurrence (calculated difference between the present year x and the last event $x-1$).

II. BACKGROUND

Crowdsourcing may be utilised in many disciplines requiring human input and where computer algorithms for automating tasks are not easy to implement and where researchers can access crowds, their group intelligence, visual processing capabilities, and motor-skills. Not surprisingly there are examples of such studies in pharmaceutical research [7], crowdsourced recruitment of patients [8], crowdsourcing in software engineering [9], in natural language processing [10], and in scoping government works [11]. Today, there are more than 75,000 articles on crowdsourcing in Google Scholar. Despite this, a search for crowdsourcing using virtual environments did not yield many results. This is surprising given that virtual environments can simulate an infinite number of scenarios in a manner that must be fruitful. One area that has very large volunteer base is represented by VGI (Volunteer Geographic Information) and although this is generally only utilised in 2D, virtual environments-based 3D-VGI is in the

process of development [12]. In another strand of work, a Leverhulme Trust funded crowdsourcing collaborative virtual environment is under development aimed at maximising the effective reconstruction of cuneiform fragments via the identification of cooperative personalities [13], [14].

More recently the AHRC (the UK Arts and Humanities Research Council) funded a £305,000 crowdsourcing project entitled 'Curious Travellers'. The project is a rapid, ethical global response to mitigate threats to cultural monuments and related heritage in Syria, Iraq, Libya and comparable regions [15].

III. CROWD BEHAVIOUR MINING

'Crowd Behaviour Mining' [2] refers to "the act of harvesting the latent behaviour or instinctive behaviour of participants, usually a crowd, and injecting the population behaviour into a pre-set context or environment within which the subjective behaviours and the context are merged." 'Crowd Behaviour Mining', referred to here as CBM is a distributed approach to solving particular

problems associated with missing information in large-scale research that is impossible to reproduce within any physical environment due to the limit of time and space. This novel approach has the potential to fill significant gaps in information space via the emergence of ‘mined’ behaviour within a virtual environment representing, for instance, a landscape. Ch’ng [2] suggests that “... by reconstructing and replicating a lost landscape, and by injecting harvested human behaviour into the context of the landscape, we may be able to gather much more information than conventional methods will allow”. And that “within such works, the collection of a sufficiently large sample of behaviours will reveal to us important trends and patterns as human activities increase.”



Fig. 2. Crowds participating in both Royal Society Summer Science Exhibition 2012 (top: “Europe’s Lost World”) and 2015 (bottom: “Stonehenge Underground”).

A. *Venues for Crowd Behaviour Mining*

When considering the opportunities for applications of CBM it is worth noting developments within museum studies. Here there has been a notable change in respect of visitor engagement within museum contexts where visitors have become active participants who receive and distribute information, contribute to exhibits and share observations with each other. Simon [16] has called such events ‘crowd-sourced exhibits’ or ‘crowd-curated exhibitions’. Here crowd sourced activities within an institution collect and shares diverse, personalised and changing content - co-produced with visitors, rather than delivering the same content to everyone. However, it should be noted that the majority of present crowdsourcing projects have involved small groups of highly active contributors providing the majority of interaction - illustrating the Pareto principle

where 20% of participants contributes to 80% of the work. The authors suggest that other approaches such as CBM, can greatly expand the definition of crowdsourcing. The shift towards visitor participation may well attract wider audiences, making museum visits a more engaging experience. Such crowdsourcing applications may be embedded within Web applications or native mobile Apps and this would invariably widen the participant base, although lessons from crowdsourcing activities also suggest that having a personal storyteller at an exhibit greatly enhances the quality of behaviour that can be garnered from participants. Unless one can design a highly engaging narrative equal that of our archaeology story-tellers, described below, one may not be able to persuade users to ‘donate’ their behaviours for any scientific cause. It also remains true that good content is the key to good exhibitions and the ultimate source of such information is knowledge generated as a product of pre-existing research.

IV. CASE STUDIES

The case studies presented derive from two recent Royal Society exhibitions in 2012 and 2015 “Europe’s Lost World” [17], [18] and the LBI ArchPro “Stonehenge Hidden Landscapes” [19]. Both exhibitions were data-driven from leading interdisciplinary research projects with global impacts in terms of technology and knowledge discovery and demonstrate the impact of digital transformation in the Arts and Humanities.

B. *Europe’s Lost World*

Europe’s Lost World, is funded by a European Research Council Advanced Grant as ‘Europe’s Lost Frontiers: exploring climate change, settlement and colonisation of the submerged landscapes of the North Sea basin using ancient DNA, seismic mapping and complex systems modelling’. The project is centred on the impact of global warming at the end of the last Ice Age and the consequent inundation of vast landscapes that had once been home to thousands of people. Amongst the most significant of these areas is Doggerland. Occupying much of the North Sea basin between continental Europe and Britain, Doggerland would have been a heartland of human occupation and central to the process of re-settlement and colonisation of north western Europe during the Mesolithic and the earlier Neolithic. This inundated landscape cannot be explored nor analysed conventionally, however pioneering work by the authors and their research groups has led to the rediscovery of Doggerland through the creation of the first maps, using seismic data, showing rivers, lakes, hills and coastlines relating to human occupation in the Early Holocene. Using these base data this project aims to transform our understanding of the colonisation and development of floral, faunal and human life during this critical period of history through the

development and application of a suite of innovative methods and research approaches.

1. Hypothesis and Gaps in the Information Space

Decisions on settlement location in the face of climate change and coastal inundation may have resulted in success, survival or even catastrophic failure for early settlers in many parts of the world. The crowd mining activity was designed to raise questions related to how individuals would respond through a palaeoenvironmental simulation that required the user to build a settlement on a coastal landscape, balancing safety and access to resources, including sea and terrestrial foodstuffs, whilst taking into consideration the threat of rising sea levels. The simulation also considered whether decisions on settlement were predicated to be near to locations where previous structures were located.

The basis of the crowd mining study was related to research on stigmergy [20], and the hypothesis that settlers fared better in their settlement choice if they were aware of previous settler activities and the experiment was constructed to assess such processes.

2. Crowdsourcing Environment and Behavioural Data

The experiment was conducted on a tabletop computer on which was constructed a theoretical landscape representing the Early Holocene period c. 12,000 to 7,500BP [17], [18], [21] and a period following the last Ice

Age when melting ice sheets ultimately submerged nearly half of Western Europe, creating bays and inlets along the Atlantic coast, and providing a new coastal ecosystem that was known to be attractive to human occupation. The tabletop interactive simulation was exhibited to thousands of visitors, with 347 participants ‘donating’ their behaviours. Detailed information is available on the published crowdsourcing study along with in-depth results [22].

3. Results

The result of the Crowd Behavior Mining is presented in Figure 3. We overlaid the total scores and heat map for all participants on the theoretical landscape. The total scores combined the attraction of coastal proximity, marine resources and terrestrial resources ranged from 0-100 overlaid on a heat map of settlements chosen by participants. High scores (in black, range from 91-100) are located at the lower right quadrant. Settlement positions of low scores (between 0 to 30 and in red) seem to be distributed quite evenly in the valleys. Intermediate scores (31-60, purple) have a pattern similar to the lower scoring groups. Scores 61-90 (yellow) show clustering and have a higher density in the areas where populations are more abundant.

The results from analysis also suggest that the process of stigmergy is present within the crowd sourced data. As seen in figure 3, participant scores stabilised roughly around their average values. It was noted that participants attempted to find a balance between coastal proximity and marine

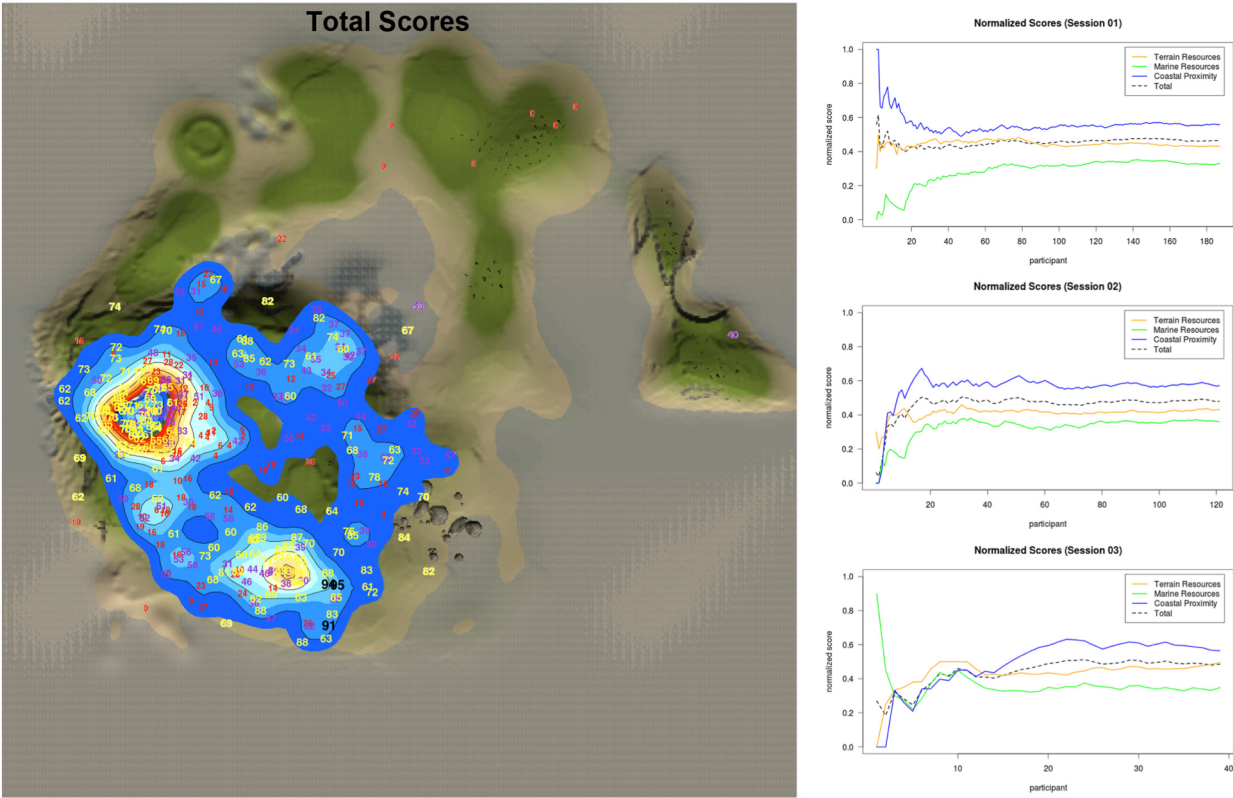


Fig. 3. Total scores and heatmap overlaid on the theoretical landscape for all participants (Left). Normalised average scores from each session (right) show that scores stabilised around their average values. This, together with Figure 2 suggests that the principle of stigmergy exists in the crowd sourced data, and that stigmergy is a possible factor influencing historic settlement choice. Image adapted from [22].



Fig. 4. Barrow types and grave goods presented to participants for selection at the beginning of the game.

resources. If settlements were built too close to the coast, flooding will occur, conversely, if they built a settlement too far away, food resources would have been out of reach and fresh water difficult to find. The study demonstrated that participants congregate (intentionally or not) around earlier settlements which had an average score initially but that participants also attempted to seek for extreme values. This resulted in both high and low scores and an average total score. However, it was also noted that some participants also attempted to seek extreme values and this is reflected in the data. However, the heat map suggests that patterns of congregation also existed within the data set and that stigmergy might be a factor influencing settlement [23].

C. *Stonehenge Hidden Landscapes*

Stonehenge is probably among the best-studied archaeological monuments in the world yet, despite several hundred years of archaeological study, much of the Stonehenge landscape remains terra incognita and, consequently, study of the most famous UK monument has been characterised by the dangerous principle of “absence of evidence being evidence of absence” [19]. The LBI ArchPro Stonehenge Hidden Landscapes Project (SHLP) seeks to tackle current limitations and gaps in our knowledge and understanding of the landscape through a survey of the areas between known monuments and using state of the art geophysical and remote sensing survey. The results of this work are now providing a highly detailed archaeological map of the ‘invisible’ landscape, providing the basis for a full interpretative synthesis of all existing remote sensing and geophysical data from the study area, as well as comparative evaluation of the results of archaeological excavation data in relation to geophysical

results. For the first time it is becoming possible to create total digital models of the Stonehenge landscape at a true ‘landscape scale’ that is not only transcending the immediate surrounds of well-known monuments within the study area, but also tying them together within a seamless map of subsurface and surface archaeological features and structures. The scale and comprehensive nature of this dataset will allow archaeologists to pose new questions about the past not possible using information only from surface remains or limited excavations. Our knowledge of the Stonehenge archaeological landscape is being transformed by integrating remote sensing and geophysical prospection with novel visualisations that combine the existing landscape with prospection and other archaeological data in a seamless fashion.

1. Hypothesis and Gaps in the Information Space

The positioning of monuments within the landscape provides an example where novel approaches may be applied to this data. During the latest Neolithic and Early Bronze Age these monuments occur as individual tumuli and coalesce into cemeteries. During the earlier Bronze Age, it is clear that many these cemeteries cluster along the edge of the Stonehenge viewshed – the visual territory of Stonehenge and which is sometimes known as the “Stonehenge Envelope”. It appears that the goal of such clustering was to provide a quality view of Stonehenge but also to be situated at a respectful distance from the monument itself. The nature of this clustering is interesting. There is the presumption that these may reflect the status of individuals or family groups but the initial positioning of the first burials was presumably the primary attractor for later decisions.

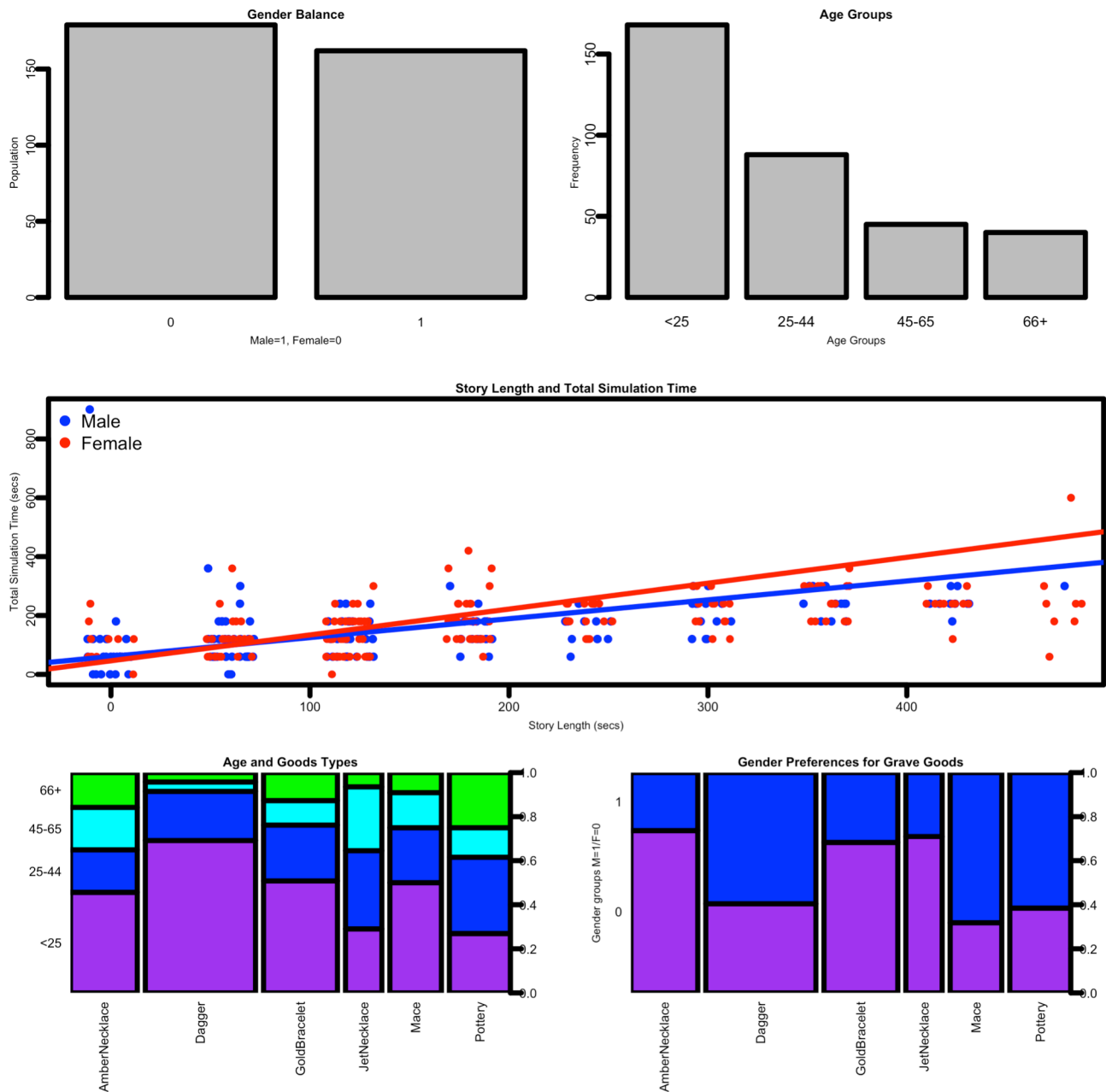


Fig. 5. Data analytics from the crowd behaviour mining activity. Top left: gender balance, top right: age groups, middle: positive correlation between story length prior to the game, and the simulation time spent in exploring the landscape and choosing the burial site (p-value < 2.2e-16, Pearson correlation test = 0.56), bottom left: age groups and preferences for type of goods selected for burial, bottom right: gender preferences for grave goods.

To test whether these factors were within operation in the game the players were allowed to choose their burial plot having been introduced to the general concept of burials during this period and including the option of being buried with a variety of objects potentially gendered and of different apparent value.

Having made a choice the players were given the opportunity to see where other players had placed their burials and the option to re-assess the position of burial according to this new information. Consequently the value of attraction was being measured.

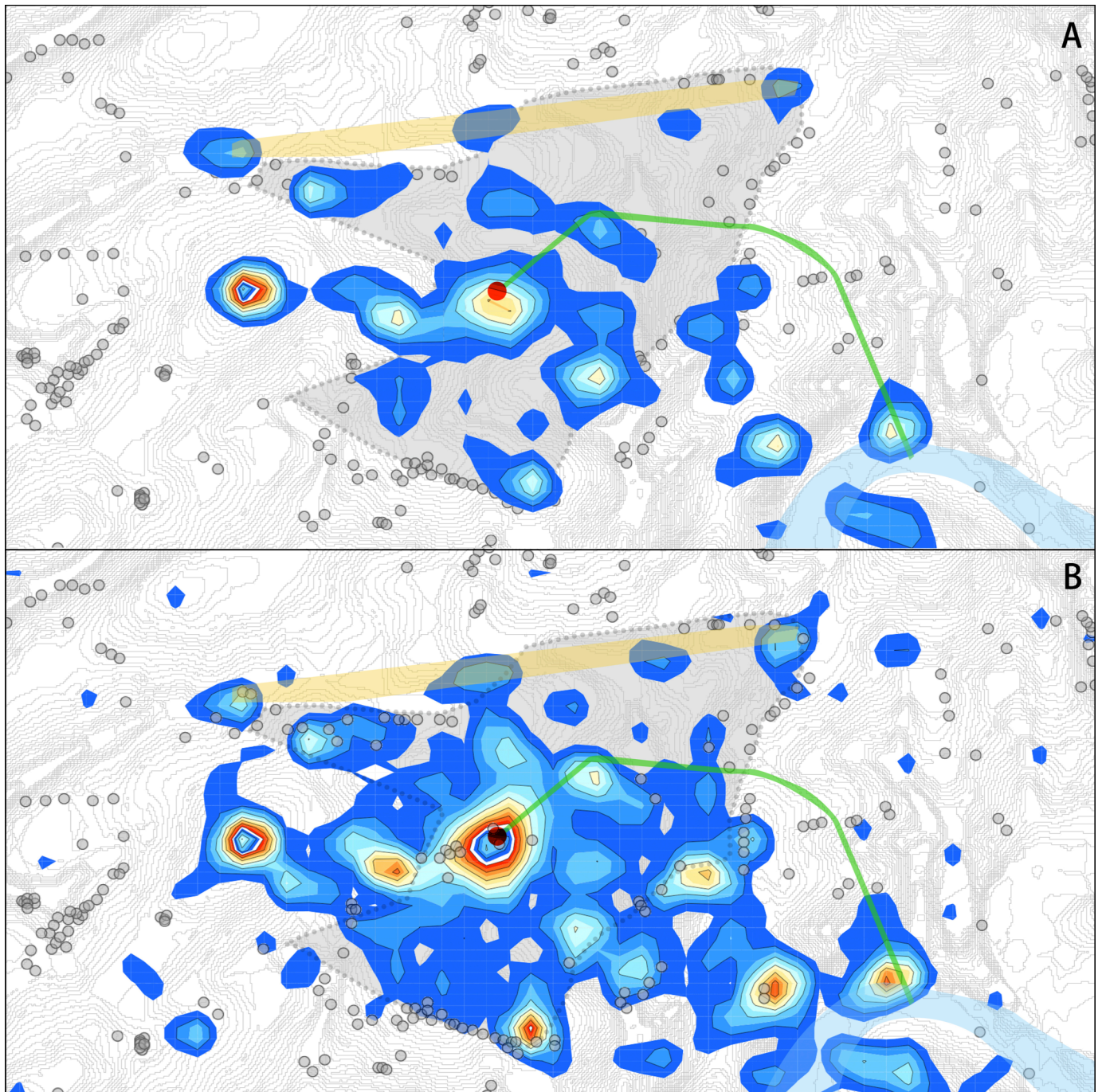


Fig. 6. Heat map showing concentration of crowd sourced burials when participants were not given the location of prior burials (top), and the change in distribution (bottom), when participants repositioned their burial places after viewing previous choices of burial locations. Stonehenge is shown as a red circle, the Stonehenge viewshed is light gray with dotted edges, the Greater Cursus is beige, the Avenue is represented as a green line and original barrows are represented as grey circles.

A secondary issue related to grave goods. There has in the past been the tendency to presume that grave goods are gendered and, in the absence of data on the sex of burials, to presume an association of specific goods with specific genders. Here the participants were provided an unconstrained choice of grave goods including weapons, ornaments, utilitarian items (a clay pot or beaker) and

special goods (amber/gold) and their choices assessed with this in mind.

2. Crowdsourcing Environment and Behavioural Data

As with Europe's Lost World, the Crowd Behaviour Mining activity for Stonehenge Hidden Landscapes was also conducted on a tabletop computer.

We used prior knowledge of well-known monuments around Stonehenge within the crowdsourcing application as a basis for the map and extruded the terrain surface and reconstructed a 3D representation of the Stonehenge landscape (YouTube video of the process: [24]). A secondary landscape with a transparent map of the contours was constructed and draped over the landscape for clarity. A layer including Neolithic monuments, Bronze Age barrows and Stonehenge itself was added on the terrain. The primary driver for burial monument location, the map representation of the views to and from Stonehenge (also known as the Stonehenge envelope) was initially hidden from view. Two modes of navigation were introduced – bird’s eye-view and first person view. User interface elements include navigation and zooming features, whilst a 3D first person view option was clearly an important factor when making a choice. A burial placement button, view-switch, and view contour of landscape options were also provided. We introduced game-mechanics such as timers and sound effects into the crowdsourcing application and titled it “Bring Out Your Dead!” At the start of the game, Stonehenge, Bluehenge, the Greater Cursus and the Avenue was shown which proceeded with five sections – 1) Story telling by project archaeologists where participants were provided with an introduction to the subject and the archaeology of Stonehenge. This included a description of the primary monuments, the nature of burials in the Bronze Age, the type of burials with and without grave goods and the potential for specific barrow types (Figure 4) to be seen according to their location. 2) The user chose a grave good out of six and one of seven burial mound types (Figure 4), 3) Users were then given the opportunity to pick a place in the context of the landscape to ‘bury your dead’, 4) After burying the dead in action 2, all the past locations of participant burials were revealed and the participant were given the chance to change burial position having looked at past participant burial locations, 5) The game was completed by showing users all the burial mounds and the area viewed from Stonehenge.

As in any Royal Society exhibitions, thousands of visitors either viewed or played the game. We gathered data from a total of 341 participants, 7 out of 348 were removed due to data collection errors. The following independent variables were measured.

- introTime – the time devoted to the introduction to the game and the archaeology of Stonehenge
- startTime – upon game start
- navTime – the time it took participants to navigate around the landscape
- buriedTime – the time the participants click the confirmation button for burial
- stigmergyTime – records the time of the second burial, after the participants are shown other participants’ burial positions, this is an incremental option measuring stigmergy
- gender – 1 as male, 0 as female figure *.* Figure *.*

- age – five levels of age groups ("<25" "25-44" "45-65" "66+")
- goods – 6 goods to choose from ("AmberNecklace", "Dagger", "GoldBracelet", "Jet Necklace", "Mace", "Pottery"). See Figure 4. It should be stated that the artefacts represented are generic and derived from a wider geographic area and timescale.
- barrows – 6 barrow types to choose from ("BellBarrow", "BellBarrowBank", "BowlBarrow", "DiscBarrow", "PondBarrow", "SaucerBarrow"). See Figure 4.
- posx, posy, posz – first burial position
- spostx, sposty, spostz – stigmergy burial position (after the participants are shown other participants’ burial positions, this is an incremental option measuring stigmergy)
- inViewShed – is the burial position within the viewshed, or visual territory of Stonehenge?

3. Results

A key aspect of the game was the introduction and the story presented by the archaeologists. Not surprisingly the time expended in telling a story was reflected in the time spent in the simulation (Figure 5 middle, p-value < 2.2e-16, Pearson correlation 0.56) – presumably as a reflection of the total of information being considered by the participant.

With respect of good types some objects proved attractive to specific age groups – younger groups aged <25 were clearly attracted to weaponry with females tending to choose ornaments (Figure 5, bottom left).

More interesting in this respect is the decision making in respect of burial placement. The majority of participants were aware that optimal barrow placement was highly visible but that proximity to Stonehenge may not be optimal either for visual reasons or with respect of cultural taboos. Consequently, the heat map of initial choices indicates a clear preference for high places (Figure 6A) – generally without any consideration of actual intervisibility with Stonehenge and also directly around Stonehenge itself. Small numbers of participants chose the actual positions of larger barrow groups.

When provided with the option to move on the basis of knowledge of actual barrow positions it is clear that many participants changed their decision (Figure 6B) and the barrows were dispersed across the landscape. However, relatively few new clusters emerged and some significant areas – most notably the key barrow cluster on the King Barrow Ridge to the east of Stonehenge- were largely ignored despite the presence of many monuments at this position. Many of the positions chosen remained outside the visual envelope and some positions – such as the ends of the earlier Greater Cursus monument- appear to have been attractive simply because the monument was present within all the screens in which decisions were made.

V. CONCLUSION

The results from both sets of data are of considerable interest. However, the relative lack of coherence regarding the data from Stonehenge may be a consequence of the relative complexity of the game. Many novel concepts had to be introduced in respect of the nature of burial, burial goods, positions of monuments and potential taboos, etc. In comparison, the North Sea game was simple and the primary drivers, the rise of sea level and availability of food were perhaps more readily comprehensible in comparison. It is also clear that on occasion, particularly in respect of the North Sea data set, some decisions were driven by the desire to choose extreme positions – perhaps simply to see what might happen as a consequence. Despite this, it is also clear that the data set generated through these studies are rich and worthy of further study and that lessons can be learnt regarding the design of such experiments. These issues and the detail of the results will be the subject of further analysis and publication.

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